

# Compilation and Synthesis for Fault-Tolerant Digital Microfluidic Biochips (DMBs)

**Alistar, Mirela**

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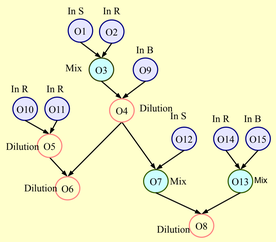
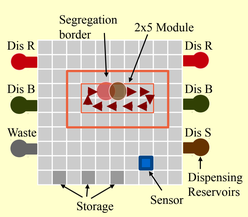
**Mirela Alistar** **Advisors: Paul Pop, Jan Madsen**

## Biochemical Application Model




A biochemical application is modeled as a directed graph, where the nodes represent the operations and the edges represent the dependencies between them. Examples of operations are: dispensing, mix, dilution, optical detection, merge. Droplets are transmitted through the edges from one operation to its successor operation. An operation is ready to execute when its inputs have arrived.

## Biochip Architecture Model

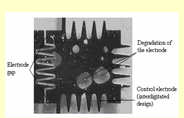



A biochip architecture is modeled as an array of electrodes. The biochip contains devices such as dispensing and waste reservoirs and sensors. Sensors can be used to determine the result of the bioassay or for error detection.

Operations execute within specified areas called *modules*, which can be placed on any electrodes of the biochip. A mixing operation is executed when two droplets are moved to the same location and then transported together according to a specific pattern. A split operation is done by keeping the electrode on which the droplet is resting turned off, while applying concurrently the same voltage on two opposite neighboring electrodes. Dilution is a mixing followed by a split.

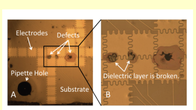
These architectures are general-purpose and highly reconfigurable.

## Challenge: Faults




Insulator degradation

Unbalanced split



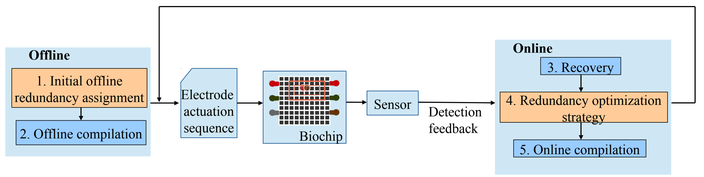

Dielectric breakdown

During the execution of the application, the volume of droplets can vary erroneously due to transient faults. The errors propagate throughout the entire application, affecting eventually the result of the bioassay. Biochemical applications have sensitivity to faults during runtime, such as an unbalanced split.

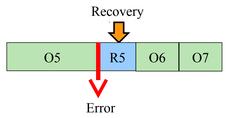
Permanent faults, introduced during fabrication, can prevent the execution of the application.

Hence, there is an imperative need for design methodologies for fault-tolerant DMBs.

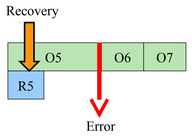
## Runtime Compilation for Error Recovery




## Recovery Techniques

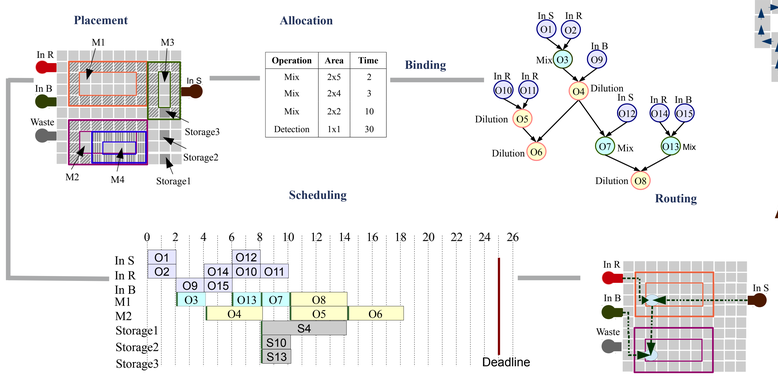



**Time redundancy** re-executes the erroneous operations *after* the error was detected.

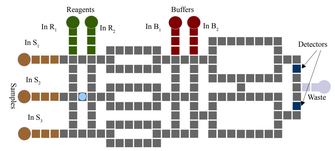



**Space redundancy** creates redundant droplets *before* the error was detected.

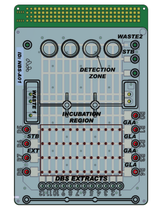
## Compilation Tasks



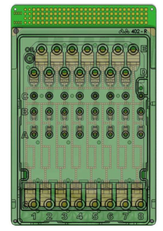

## Application Specific Architecture




Application-specific biochip model




DMB for Newborn Screening (Advanced Liquid Logics, Inc.)



DMB for Sample Preparation (Nugen, Inc.)

## Problem Formulation

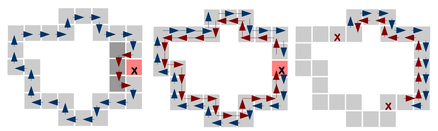
**Given**
- A biochemical application
- A library of components
- The number *k* of permanent faults

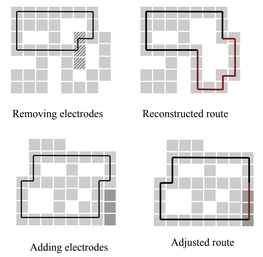
**Determine a**n application-specific architecture so that
- the cost is minimized and
- the application completes within deadline
- for any occurrence of the *k* permanent faults

## Cost Evaluation

$$Cost_A = \underbrace{\sum N_{M_i} \times Cost_{M_i}}_{\text{Component cost}} + \underbrace{\sum N_{R_i} \times Cost_{R_i}}_{\text{Fluidic cost}}$$

## Fault-Tolerant Operation Execution






## Architecture Synthesis


Mirela Alistar mali@dtu.dk
Embedded Systems Engineering Section, DTU Compute

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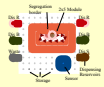

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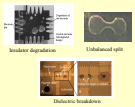

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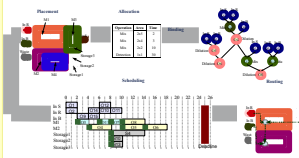

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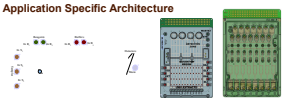

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Component cost Fluidic cost

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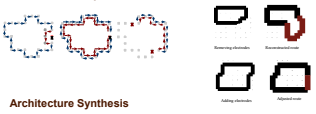

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